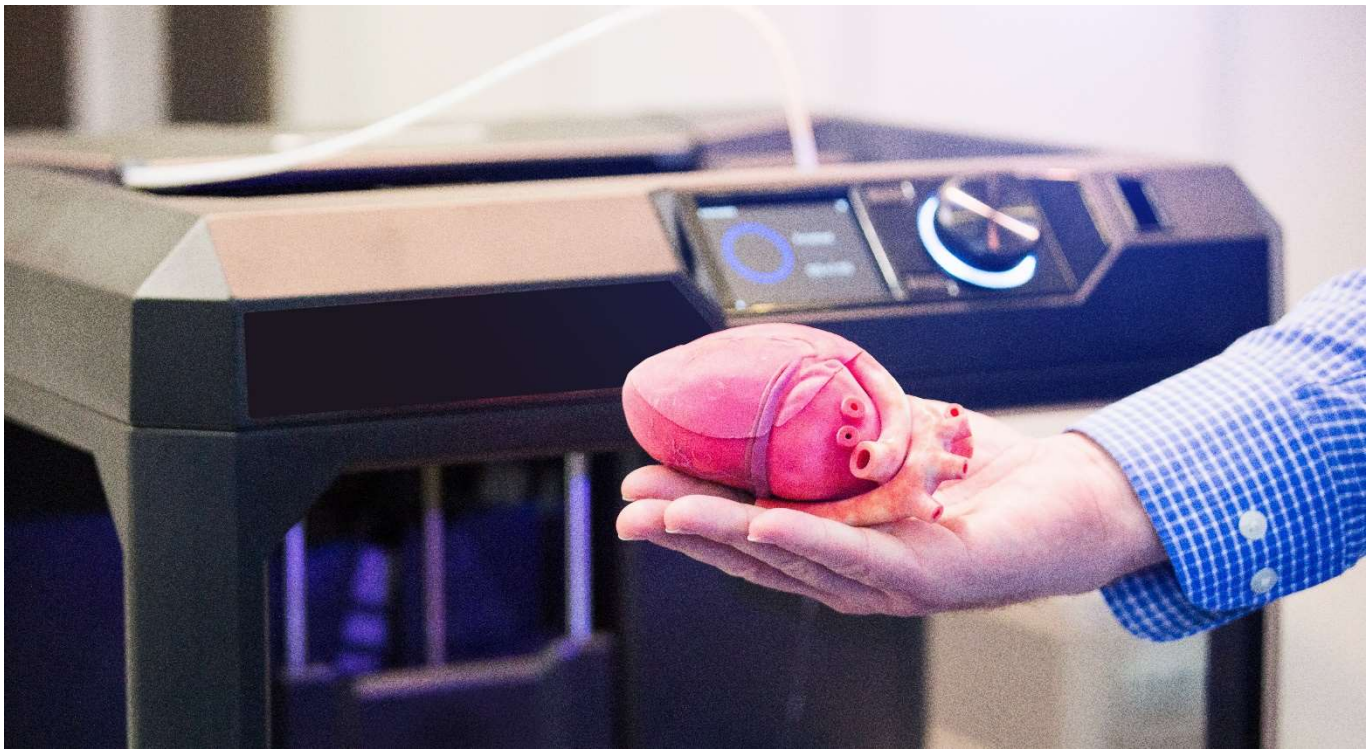

THE USE OF 3D PRINTING IN MEDICINE - AN OVERVIEW OF CURRENT ACHIEVEMENTS AND POSSIBLE WAYS OF DEVELOPMENT IN THE FUTURE

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ABSTRACT

3D Printing also known as additive manufacturing is the one of most rapidly evolving technique in contemporary medical use. Because of decreasing cost of 3D printers an extended availability and accelerated development of this technique can be spotted at present.

This paper reviews the current medical applications of additive manufacturing. Moreover, it discusses the problems and challenges standing on the way of this revolutionizing technique. 3D Printing helps students in learning anatomy, surgeons in preoperative preparation and mainly patients by possibility to create personalized prosthesis. Contemporary almost 99% of all hearing aids are printed by 3D printer. The application of 3D printing in combination with medical imaging techniques undoubtedly enhances forensic medicine. It can be used to print models which are appropriate to evidence presentation in the courtroom and settle the final cause of death.

A lot of futurists claim that future of that technique is heading towards printing functional organs, which will be able to replace human organs. Based on these considerations, it can be concluded that the boundaries of future medicine are designated only by our imagination.

BACKGROUND

Dynamic development of 3D Printing technology has been seen in recent years. Their medical applications are expected to revolutionize some fields of medicine [1, 2]. The biggest benefits can concern orthopaedics, plastic surgery and neurosurgery [2, 3]. 3D Printing also known as an additive manufacturing is expanding rapidly. It provides increased productivity, cost-effectiveness and greater availability for patients [4]. Nowadays we're able to create simple tissues, customized prosthetics, implants, anatomical models for students and surgeons to preoperative preparation. However, printing technique of more advanced objects such as human organs will need some time to evolve mainly by actual technical restrictions [4].

WHAT IS 3D PRINTING?

3D printing also known as stereolithography (STL) was invented by Charles Hull in 1984 and patented two years later [4]. From those days files with .stl file extension are gold standard for transfer data between computer with computer aided design software (CAD) and 3D printer [5]. Program called 'Slicer' converts data from STL file to G-code. It contains divided 3D object into a lot of 2D horizontal cross sections. They're saved into coordinates in binary code and transferred to printer. This coordinates contain position and temperature of the extruder, texture and thickness of the printing material. Object is printing layer by layer by 3D printer extruder which is moving along the x-y plane above the platform. Nonetheless, several types of 3D printing can be distinguished. These include: Stereolithography (SLA), Selective Laser Sintering (SLS), MultiJet modelling (MJM), Fused Deposition Modelling (FDM) and Binder Jet Technique [5, 6]. In actual fact, technical capabilities enables to create objects from very different materials [5, 6]. As a result of investigation not only a plastic materials can be applied but also ceramics ones including: wax, bronze, silver, stainless steel and titanium [6]. Each technique of 3D printing requires different material. As an example, e.g. Binder Jet Technique uses ceramics and glass which yields in fast speed and variety of colours [7]. Nevertheless, the disadvantage in the shape of low durability of printed objects can be highly does occur [7].

SURGICAL PREPARATION

3D printing facilitates specialization of preoperative planning relying on two-dimensional radiographic images. MRI or CT scans received on imaging examination are converted to computer-aided design file [8]. Based on it 3D printer creates tangible, mapped model of patient's anatomical structures and organs. They are made of semi-translucent polyvinyl alcohol or acrylic resin. The application of these materials, provide similar structure to human tissue [2]. The benefit of this solution composes an opportunity to train surgery on high-quality 3D anatomical models taking into account the safest surgical corridor or a patient's specific anatomy. The use of an exact replica is preferred in case of post-traumatic craniofacial, skull base, cervical spine, osteoplastic flap reconstruction of frontal sinus defects in otolaryngological surgery that can be simulated beforehand [9, 10]. In orthopaedic surgery models are used to planning bony fixation plates implantations or pathologic lesions excision [11, 12]. 3D-printed models have been used in numerous cases in cardiovascular surgery: aortic aneurysm removal, recreating a calcified aorta, treating congenital heart disorders, testing catheter equipment and practicing the procedures [13, 14, 15]. Planning and preparing presurgical tumour removal from a skull and deep tissue is done using 3D printing [16]. Also in urology there is a request for additive manufacturing to plan partial nephrectomy for renal tumours [17]. 3D models can be useful beyond surgical planning cardiac and hepatic transplantation because it allows to minimize loss of donor's tissue to fit the receiver's anatomic topography [2].

BIOPRINTING TISSUES AND ORGANS

Bioprinting, that is next application of 3D printing, has expanded for about 15 years as an utmost solution for tissue supplied with blood vessels [18]. This technology was supposed to be an answer to shortage of human organs able to transplantation. In addition, there is a problem to find donor who is tissue match [1]. The simplest solution could be ability to build organ from patient's own cells. Reduction of tissue rejection and limitation of necessity lifelong taking immunosuppressants are considered as the next benefits [1]. Bioprinting is a procedure of printing with adequate use of biomaterials and live cells of human body [4]. Various types of tissues are analysed as a possible to achieve, for example blood vessel, skin, cartilage, bone, cardiac tissue, and liver [19]. A flagship method of bioprinting is isolating stem cells from patient's tissue samples, stimulating by many grow factors, laboratory proliferation and place them onto 3D – printed scaffolds which determine further differentiation into organ-specific cells. Nowadays physicians obtain a knee meniscus, spinal disk, cartilage's and bone's tissue, even apply inkjet 3D printing technology to receive heart valve [5, 20]. One of the most important application of bioprinting is autogenous ear reconstruction. The method is based on using 2D template of contralateral ear as a model and turning away along its vertical axis to receive contralateral ear [21]. Ground-breaking achievement became an opportunity to treat congenital tracheobronchomalacia, a weakness and collapse of the tracheal support cartilages and airways. With the aid of 3D-printer and babies CT images doctors prepared and surgically implanted onto patient's left bronchus accurate modelled, bioresorbable tracheal splint [20]. In case of bones presence of living cells have not been obtained. The ability to adjust shape and size allows individualization of prostheses. In future these prostheses will contain living vascularized bone tissue which will be take part in growth and remodelling and will be a form of therapy for young people with bone defects. It especially enables the reduction of reoperations and better long-term mechanics [22].

PROSTHESES AND IMPLANTS

The development of 3D printing unquestionably facilitates better fit to each patient's anatomy. Through obtained X-rays, CT scans it is possible to make personalized in shape and size implants sometimes within 24 hours. There are many benefits of preparing implants and prostheses by 3D printer. It is important to adjust mechanical properties in different regions depending on the forces acting on the implant. The porosity of the implant is important as proper implant adherence to bone occurs through bone ingrowth into the pores of the prosthetic and it simplify biodegradability of the scaffold on account of reduced material presence. Now dental, mandibular, maxillofacial, spinal, and hip implants are performed. Also in neurosurgery there is a request for customized skulls for casualties. Parts of bones of the skull have to be removed to allow the brain to swell and do not allow an increase in intracranial pressure. The cranial plate which is later fixed must be perfectly matched [23]. One of the most successful commercial cases for 3D printing are Invisalign braces. It is estimated that 50,000 braces are printed every day. These custom-made orthodontic aligners are removable, clear and customized [24]. Also 3D printed hearing aids development is observed. Near 99% of all hearing aids are printed by 3D printer. Unique shape adapted to patient ear canal's goes hand in hand with efficient and economical production [23].

FORENSIC SCIENCE

The deployment of 3D printing has had a significant impact in forensic imaging. Main task of forensic medicine is to determine the mechanism of an injury or disease and to identify the weapons used to cause those injuries. This method fully respects the dignity of the deceased and is consistent with medical ethics [25]. Models of bone fractures, cardiac infarctions, ruptured organs demonstrate radiologically visible pathologies. Precision of fabrication and colour facilitates profound understanding of laypersons rather than volume rendering or 2D reconstructions. 3D printing enables the evaluation of antemortem clinical data. In consequence, it was possible to reconstruct fractured skull from a blunt force head injury and aid in weapon identification and determination of the mechanism of injury leading to death. A similar use of 3D printing is the recreation of a hammer injured skull which helps to deduce the cause of injury. It has been proved that comparable with traditional methods results can be obtained [25].

BENEFITS FOR EDUCATION

Additive manufacturing has become more commonplace, because this technology is at present cheaper than a few years ago. Many universities decide to use 3D printing to raise their standards. The educational applications of 3D printing focus on organs not only in the state of health but also illness. Recently, a model of a polypeptide chain model has been produced using 3D printing and is capable of mimic folding into secondary structures. It is possible due to compliance with bond rotational barriers and degrees of freedom considerations [26]. Because of that students who have had opportunity to use this model are able to comprehend peptide structure that researches confirm this. What is important, the use does not have to be limited only to biomacromolecules, other models could be utilized to help the understanding of protein maturation [5]. Bio-models may help patients to understand their disease during medical consultations and training surgical trainees [27].

ORGAN PRINTING – NEAR FUTURE?

Personalization is the main direction of medicine development. 3D printing is expected to resolve many contemporary problems with advanced tasks. In case of transplantology an additive manufacturing may help with shortage of organs through organ printing. It has been estimated that in less than 20 years scientists create a fully functioning printable heart [27]. The main problem of this technology is proper vascularisation of tissue. When the thickness of printed tissue exceeds 150-200 micrometres the oxygen diffusion becomes limited [28]. It is expected that improvement of efficient vascular network integration between host and transplanted tissue will occur soon. Little availability of kidneys, livers and hearts forces the development of 3D printing, because these organs require adequate vasculature to bring glucose, oxygen and nutrients and take back metabolic products [29]. Bioprinting with use of bionic properties allows to design precisely every tissue through emplacement differentiated adult or stem cells in biomaterial scaffolds. That has not been possible to achieve so far. Last researches from many countries confirm possibility to bioprint a functional and perdurable network of vessels [30]. Another future application of additive manufacturing is in situ printing, which happens in patient's body during operation. Furthermore, an opportunity to cure damages and losses of different tissues is very possible. Nevertheless, filling the wound bed in skin lesion by keratinocytes and fibroblasts have already occurred [29].

CONCLUSIONS

3D Printing has become very useful tool in medicine with enormous future expectations. These days it can be used for preoperative planning, anatomy training and patient education. Additive manufacturing is already significant help in forensic medicine. It also brings new hope to orthopaedics patients who are disqualified for a prosthesis due to too large bone defect. However, printing more advanced tissues and organs still constitutes a great challenge.

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ABBREVIATIONS

CAD – computer aided design software
FDM – Fused Deposition Modelling
MJM – MultiJet modelling

SLS – Selective Laser Sintering
STL – stereolithography

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